A new method for determining the parameters of close double systems of supermassive black holes

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We propose a new method for calculating the parameters of the orbits of double supermassive black holes (SMBH) using only multi-frequency monitoring data in the radio band. Our results suggest that 3C 454.3 may be the most massive close double systems of SMBHs.

The shape of the flux density change during the unusual flare in 2014-2020 may indicate the coincidence of planes of the accretion disk (AD) and the orbits of the companions.

We use a novel combination of data monitoring studies in the radio range and a new method for determining system parameters to obtain estimates of the diameter and thickness of AD 3C 454.

According to our study, due to precession, companions will leave the central parts of the AD in a few years if the AD retains its stability and does not collapse before that time. Estimates of the values of changes in the orbits of 3C 454.3 companions are made. The obtained values of changes in the orbits do not allow them to be detected by modern methods.

The calculated lifetimes of the 3C 454.3 system show that this is a short-lived object in the Universe with a lifetime of $5 \cdot 10^4$ yr.

Table 1. Results of harmonic analysis of multi-frequency monitoring of 3C454.3. The first row contains results for all the specified frequencies for the entire observation period since 1966. The second row contains also data for all frequencies, but for the time interval of observations from 1966 to 2008. The third row shows the same data, but for the time interval from 2009 to 2020.

$T_{1966-2020}$ (years)	14.0 ± 1.4 ($T_{pr,obs}$)	7.3 ± 0.7	2.3 ± 0.2 ($T_{orb,obs}$)	1.1 ± 0.1
$T_{1966-2008}$ (years)	14.8 ± 2.1	7.6 ± 0.9	2.3 ± 0.3	1.1 ± 0.15
$T_{2009-2020}$ (years)		7.0 ± 1.1	2.2 ± 0.3	1.1 ± 0.15
$T_{\gamma^2/(1+z)}$ (years)	188 ± 19 ($T_{pr,source}$)	100.0 ± 10.0	$31.0 \pm 2.8)$ ($T_{orb,source}$)	15.0 ± 1.5

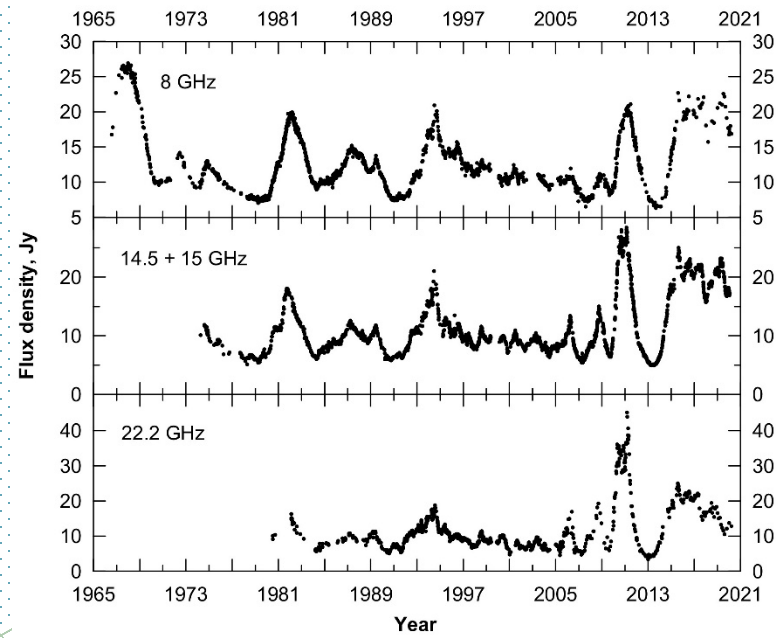

Fig. 1. Data of 3C454.3 monitoring for the period 1966 to 2020.

Table 2. Values of the 3C454.3 companion masses for the three values of the orbit of the companion.

Radius of the companion's orbit, cm	Mass of the companion, $M_\odot$	Mass of the central SMBH, $M_\odot$	Lifetime in years
$6.0 \cdot 10^{17}$	$1.6 \cdot 10^{10}$	$5.7 \cdot 10^{10}$	$1.3 \cdot 10^4$
$4.5 \cdot 10^{17}$	$6.8 \cdot 10^9$	$2.4 \cdot 10^{10}$	$5.5 \cdot 10^4$
$3.0 \cdot 10^{17}$	$2.0 \cdot 10^9$	$7.0 \cdot 10^9$	$4.2 \cdot 10^4$

Monitoring at frequencies of 8 and 14.5 GHz was performed on the 26m radio telescope of the University of Michigan Observatory in the period 1966 to 2012. Since 2012, observations at 8 GHz have also been made on RT-22 in Simeiz.

Monitoring at a frequency of 15 GHz was carried out using the 40m Owens Valley Radio Observatory radio telescope in the period 2013 to 2019 at a frequency of 22 GHz in Simeiz (RT-22).

Ref.: A&A, 2021, A.E. Volvach, L.N. Volvach, M.G. Larionov
Most massive double black hole 3C 454.3 and powerful gravitational wave radiation.

Using expressions (1) and (2), we define the orbit and masses of the 3C 454.3 companions (Table 2).

$$m = \frac{16\pi^2 \cdot r^3}{3G \cdot T_{orb} \cdot T_{pr}}. \quad (1)$$

$$M = \frac{16\pi^2 \cdot r^3 \cdot (0.75 \cdot T_{pr} - T_{orb})}{3G \cdot T_{orb}^2 \cdot T_{pr}}. \quad (2)$$

By expressions (1) and (2) we see that the masses of the companions depends significantly on the sizes of they orbits. This means that to great sizes for the companion orbits can lead to unrealistic values of they masses. The lower limit for the mass of the SMBH is determined by the Eddington's restriction on mass. For this reason, the resulting masses of the companions in the first row of Table 2 appear clearly improbable.

On the other hand, the total apparent luminosity of 3C 454.3 from radio to UV has been estimated as $6 \cdot 10^{47}$ erg/s. When inverse Compton contributions are added, the total luminosity may be as high as 10^{48} erg/s. If we equate this value to the Eddington luminosity, we get a minimum estimate (low limit) for the mass of the central SMBH, $M \sim 7 \cdot 10^9 M_{☼}$ (line 3, Table 2).

The estimated lifetime of the system prior to the merger for data from line 2 of Table 2 is:

$$t_{merge} \approx \frac{2 \cdot 10^{-2} \cdot c^5 \cdot r^4 \cdot (1-e^2)^{\frac{7}{2}}}{G^3 \cdot m \cdot M \cdot (m+M)} = 5.5 \cdot 10^4 yr.$$

$$< \frac{dE}{dt_{3C454.3}} > = \frac{32 G^4 M^2 m^2 (M+m)\left(1+\frac{73e^2}{24}+\frac{37e^4}{96}\right)}{5c^5 \cdot a^5 (1-e^2)^{\frac{7}{2}}} \approx 0.9 \cdot 10^{48} \frac{erg}{s}.$$